INVESTIGATION OF SOLID STATE MEMORY LOOP

Emmanuel Carmi

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

INVESTIGATION OF SOLID STATE MEMORY LOOP

by

Emmanuel Carmi

June 1975

Thesis Advisor: Jeffrey Bruce Knorr

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While most microwave memories in use are still analog, of which a majority use TWT amplifiers, solid state amplifiers are increasingly used and the performance obtained is

much better in terms of storage time. The largest part of the thesis is devoted to "Frequency Memory Loops" (FML), their method of operation, and what it takes to switch from TWT to solid state amplifiers. The remainder of the thesis examines the use of digital technology to achieve microwave storage. While analog storage is common to everyone, the digital way is diverse. Two concepts are presented.

Investigation of Solid State Memory Loop

by

Emmanuel Carmi
Lieutenant Commander, Israeli Navy
Ingéniur Diplomé E.N., École Navale, France, 1965
B.S.E.E., Naval Postgraduate School, 1974

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis presents the result of an investigation of the art of microwave memories. Both analog and digital memories are described and compared.

While most microwave memories in use are still analog, of which a majority use TWT amplifiers, solid state amplifiers are increasingly used and the performance obtained is much better in terms of storage time. The largest part of the thesis is devoted to "Frequency Memory Loops" (FML), their method of operation, and what it takes to switch from TWT to solid state amplifiers. The remainder of the thesis examines the use of digital technology to achieve microwave storage. While analog storage is common to everyone, the digital way is diverse. Two concepts are presented.

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I. INTRODUCTION

A. GENERAL

The microwave memory loop has been known for a long time in electronic warfare and other related areas. The purpose of the device is to store an intercepted signal's frequency and to reproduce it on demand.

The concept of an FML is simple; a signal is intercepted and circulated in a loop. The loop consists of an amplifier, a delay line and a filter.

TWT were found to be very suitable amplifiers. However, with evolving technology an investigation was made into the possibility of incorporating solid state amplifiers in the memory loop. These attempts were greatly successful at frequencies up to 4 Ghz. However, technology has not yet been able to produce adequate solid state amplifiers at higher frequencies.

Industry tends to divert from this method of frequency storage. Basically, the digital era and the abundance of possibilities led to the study and development of systems in which the wave form, rather than the frequency, is retained in a digital form. Three main constraints are still encountered:

1. The response of VCO is yet too slow for swift reproduction of the signal.

2. The rate of sampling is not high enough, introducing

a slight distortion of the output signal.

3. The instantaneous bandwidth of present systems is not very impressive (about 200 mHz).

B. WHAT ARE MICROWAVE STORAGE DEVICES GOOD FOR?

As far as the analog FML devices, they are the heart of any microwave repeater where intrapulse modulations are of no concern, and a pulse containing the carrier frequency is to be reproduced at a desired time.

Any Fire Control (FC) deceiving system makes use of an FML. The logic of operation is as follows: The pulse is intercepted, stored and retransmitted with an increasing delay to create a radial target velocity in the enemy's system. The deception of the direction depends on the type of angle tracking. If the deceiving system is to be operated against a conical scan radar, the reproduced stored signal will be amplitude modulated at the conical scan rate with an enhancement of a particular side in order to turn away the locked antenna.

The system could also be used to plant false targets in a search radar, and as a beacon repeater for navigation purposes.

The only digital microwave storage device looked at could do everything done by his older brother and more. Since the device stores the wave form rather than the carrier frequency, intrapulse modulation could also be deceived. Furthermore, digital devices could be used as a communication repeater, correlator and more.

The understanding of where microwave storage devices might be used has no bearing on the understanding of how the device works.

C. REMARKS

The following assumptions were made in this paper:

- The signal gets to the memory while all preamplification problems are solved as well as dynamic range and sensitivity.

- The amplification of the reproduced stored signal for transmission was not considered as part of the memory system and hence was not dealt with.

II. DESCRIPTION OF THE "FREQUENCY MEMORY LOOP" (FML)

A. OPERATION

Frequency Memory Loops fall into the category of memory receivers. The information to be retained from the signal is the carrier frequency.

The problem arose when it dealt with short pulses, .1 to 10 μsec. It is inconceivable to sample such high frequency in such a short time. In such cases, it was decided to stretch the pulse. By stretching the pulse, a narrow spectrum is obtained and a better knowledge of the carrier frequency is achieved.

The stretching operation can be accomplished by the so-called memory loop consisting of a microwave delay line, an amplifier, and couplers to couple in the intercepted signal and to couple out the stored frequency for further use.

The very simplified explanation of the loop is as follows (Fig. 1). The input RF pulse is coupled to the loop, delayed, amplified, filtered, delayed, amplified, filtered, and so on, circulating in the loop forever if the components were ideal. Part of the energy is coupled to the load, providing it to the user.

To obtained memory performance and regeneration at any frequency in the band, the small signal gain of the amplifier must be in excess of all losses summed up in the loop across the band. Under power limiting conditions of the amplifier,

a gain of unity for the loop should be obtained. The successful operation of such a loop is critically dependent upon the proper choice of the components as well as the input signal level.

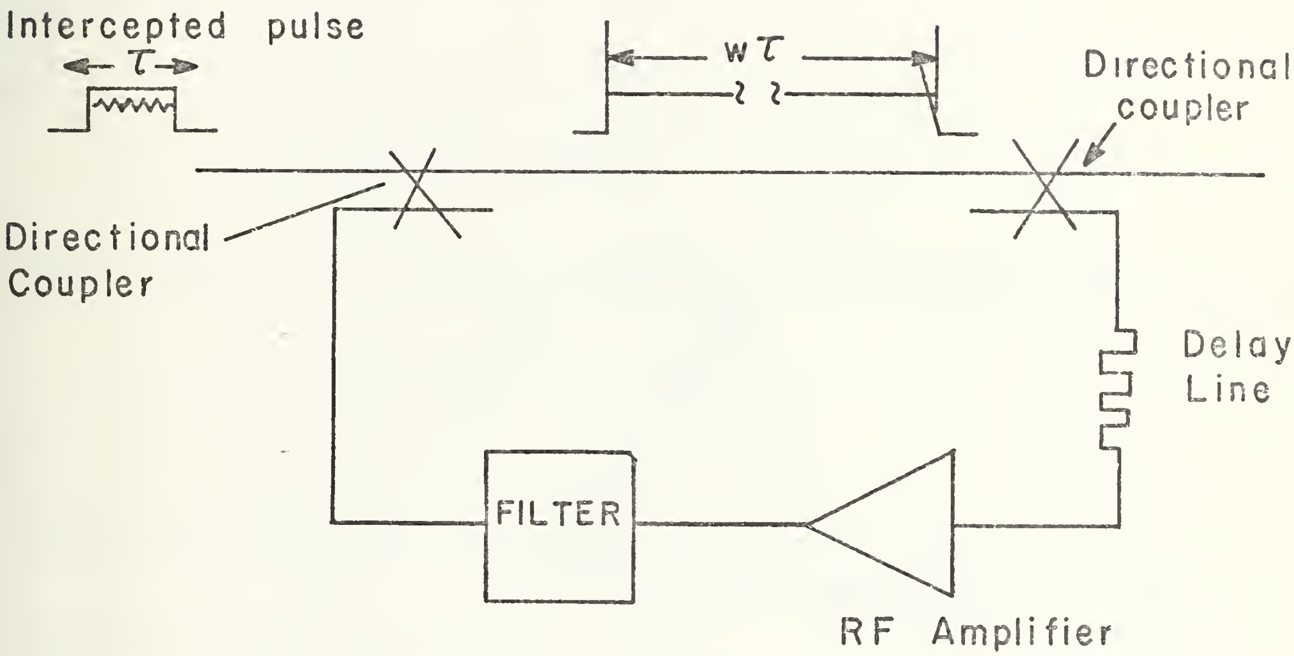


FIGURE 1. Off-Line RF Memory Loop

B. DYNAMIC OUTLOOK OF THE FML

Most of the publications concerning FMLs were concerned with the dynamics of the loop. This fact is largely attributed to the commonly used TWT amplifier in the loop.

The input/output characteristic of the TWT as shown in Fig. 2 demonstrates an increase in gain compression as the input power gets larger. This is not true for solid state amplifiers, hence in recent publications the dynamics is overlooked.

For the sake of completeness, the following example is presented; it might have the quality to more visualize the operation of the loop. In Fig. 2, suppose a -35 dbm input signal enters the loop amplifier. At the amplifier's output there would be -3 dbm (pt 1) turning around the loop once, the signal would be attenuated and would attain -26 dbm (pt 2).

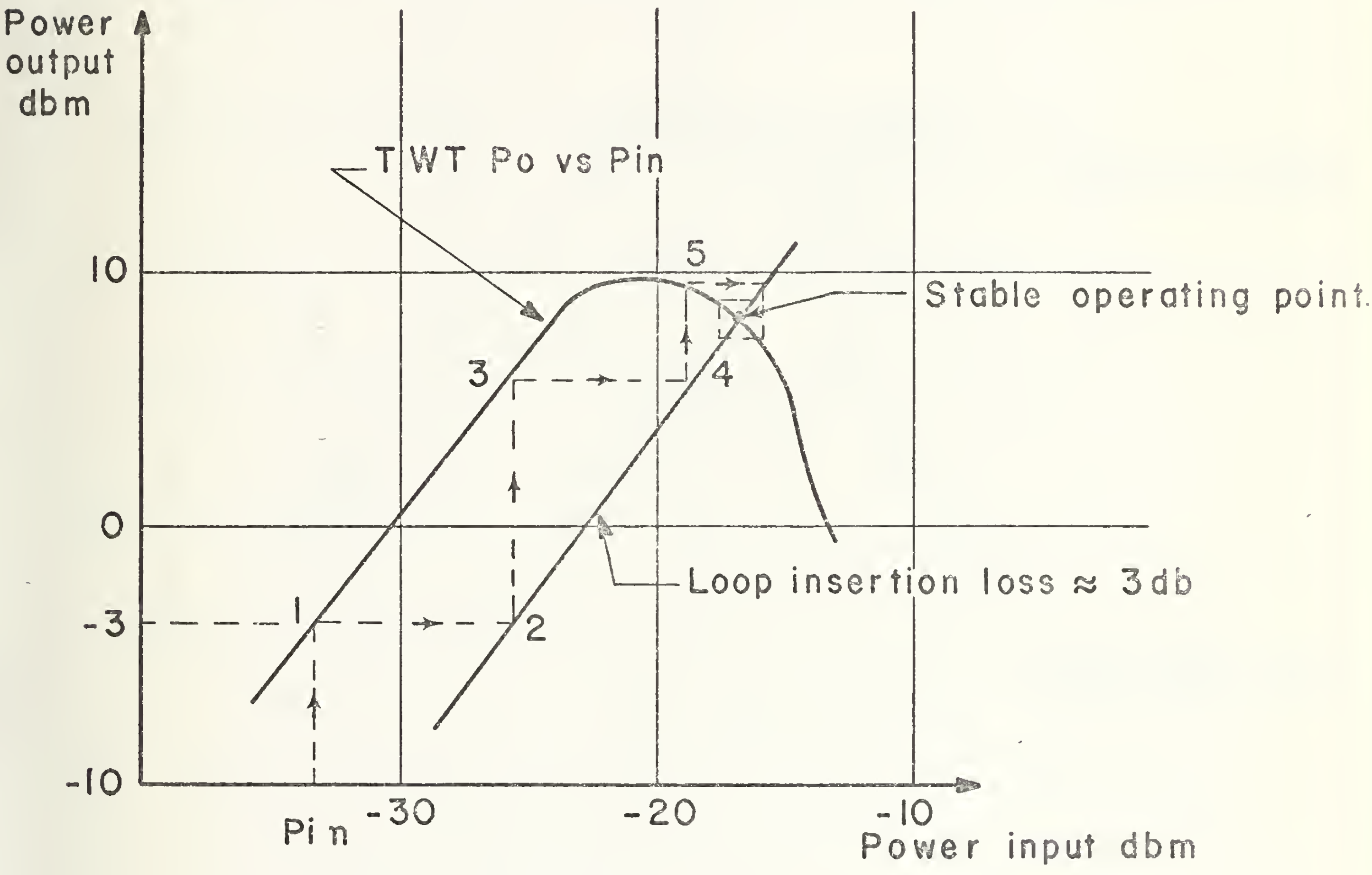


FIGURE 2. Dynamics of FML

Going on with the same logic, the stable operating point is attained after a certain number of turns. The choice of the location of the stable operating point on the amplifier's curve is of concern when TWT amplifiers are used. What is sought is a rather flat overdrive region (for TWT criteria, see references [1] & [2]).

In order to understand better why it is important to choose a proper operating point, Fig. 3 shows what would happen if the operating point was badly chosen.

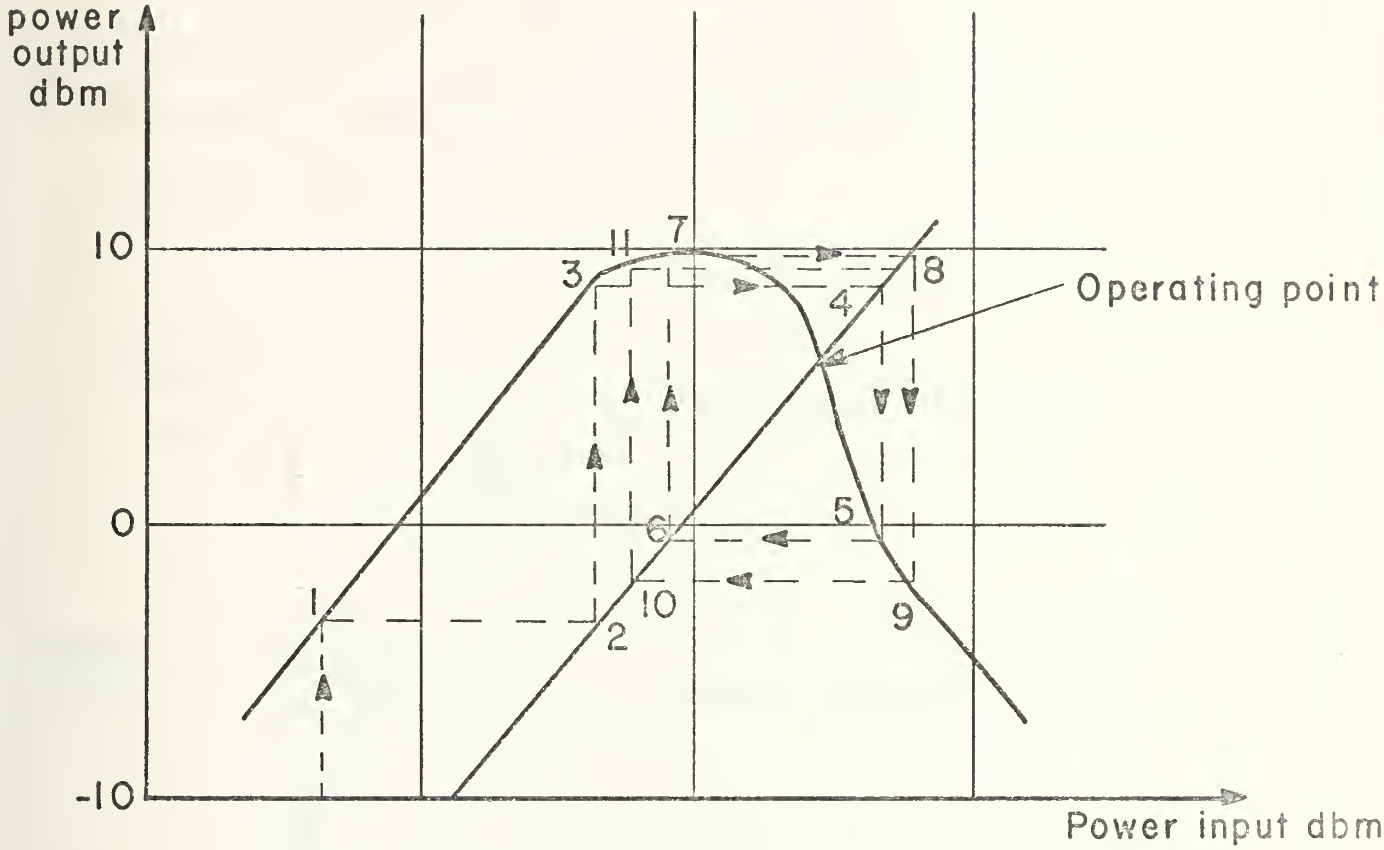


FIGURE 3. Badly Chosen Operating Point

If the same input/output characteristic as in Fig. 2 was chosen, but with a different loop insertion loss, which in turn introduces a new operating point. Following the same logic previously explained, one could notice that no matter how many times the signal will turn around, stability will not be achieved.

C. NOISE CONSIDERATIONS

1. Definitions

Before the effect of noise on the loop is discussed, it should be defined what is meant in this paper by some terms and not yet agreed upon in different papers. Fig. 4 shows what is meant by gain compression, noise depression and noise suppression.

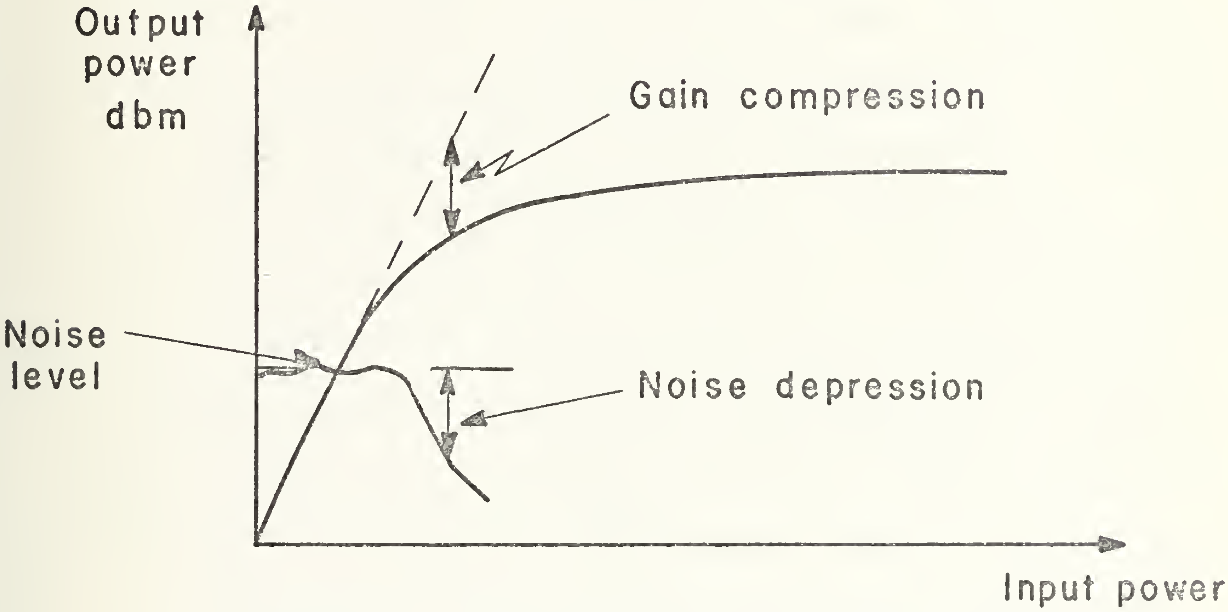


FIGURE 4. Noise Depression - Gain Compression dbm Representation

Gain Compression - The difference in db between the imaginary extended linear gain and the actual saturated gain.

Noise Depression - The attenuation of the noise level when the amplifier is overdriven.

Noise Suppression (db) = Noise Depression (db) - Gain Compression (db).

2. Noise Take Over

Although not mentioned yet, it must be understood that the small signal gain of the loop amplifier must be higher than the total losses of the components in the loop. The difference between the amplifier's gain and the absolute value of the loop insertion loss is referred to as "excess gain."

Noise is present at the input of the amplifier in addition to the signal desired to be stored. This noise can build up and finally take over. This phenomena is inhibited by the effect referred to as "noise suppression" or "capturation effect" which is manifested in all active devices. In essence, it is the mere fact that noise is depressed when the device is driven into limiting conditions by a narrow band instruction signal. In the loop, the presence of a strong signal-to-noise ratio (S/N) of 10 db will suffice for signal buildup depending on other requirements being fulfilled.

The understanding of the "capturation effect" is essential for the understanding of the loop operation. Reference [4] provides a summary to studies made by John L. Putz, W. R. Beden, J. P. Kellett and Par. V. Biggi.

In the following two subsections it is intended to clarify the noise buildup-signal absent, and noise buildup-signal present in the spirit of reference [4].

3. Noise Buildup in the Absence of an Input Signal

The model to study is that of Fig. 1.

Let:

L = total loss in the loop

B_o = filter band width

G = amplifiers small signal gain

G_n = noise gain when amplified is saturated

B = amplifiers band width

F = amplifiers noise figure

Only Gaussian thermal input noise shall be considered.

$$N_{in(1)}{}^{*} = kTB$$

The noise output from the amplifier

$$N_{out(1)} = GkTBF$$

After one circulation around the loop, the second time input to the amplifier becomes

$$N_{in(2)} = kTB + \frac{FGkTB_o}{L}$$

$$= kTB[1 + \frac{FG}{L}\frac{B_o}{B}]$$

$$N_{out(2)} = kTBFG + kTB_o F\frac{G^2}{L}$$

The third time input to the amplifier will be

$$N_{in(3)} = kTB + kTB_o \frac{G}{L} + kTB_o F\frac{G^2}{L^2}$$

If we keep going around the loop we will find that

$$N_{in(n)} = \{kTB\ 1 + \frac{B_o}{B}\frac{GF}{L}[1 + \frac{G}{L} + (\frac{G}{L})^2 + (\frac{G}{L})^3 + (\frac{G}{L})^{n-2}]\}$$

---

* The index indicates the entry time to the amplifier, 1 first, 2 second, etc. for the same signal.

Summing up this geometrical series

$$N_{i(n)} = kTB[1 + \frac{B_o}{B} \frac{GF}{L} \frac{(G/L)^{n-1} - 1}{(G/L) - 1}]$$

For the purpose of memory loop, it is common to say that 10 ∿15 db of excess gain is needed for a successful storage operation, that is to say, $\frac{G}{L} >> 1$.

The last equation can be rewritten

$$N_{in(n)} = kTB[1 + \frac{B_o}{B} \frac{GF}{L} (G/L)^{n-2}]$$

$$= kTB[1 + \frac{B_o F}{B} (G/L)^{n-1}]$$

For the typical conditions, $\frac{G}{L} = 10$ and $F = 10$, one can observe a very rapid noise buildup.

By its nature, the loop will resonate for some frequencies. It was found that for a loop with total delay time τ_o, there are preferred frequencies f_{pn} with separation

$$\Delta f_p = \frac{1}{\tau_o}$$

Those frequencies are enhanced with each circulation. In other words, there is positive regeneration for frequencies for which the electrical path length of the loop is an integer multiple of their wave length. Those add up in phase. This theory was verified by experiment [4] (see Appendix A for experiment setup).

The spectrum due to noise buildup is shown in figure 5.

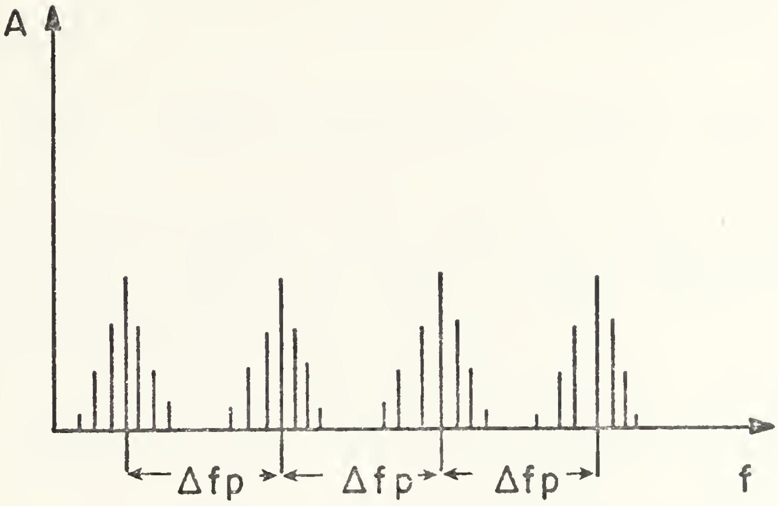


FIGURE 5. Spectrum of Noise Buildup, No Strong Signal Present

The experiment [4] has clearly shown an exponential buildup of noise. It would be of interest to know that it took fifteen turns around to saturate the TWT with noise.

4. Noise Buildup under RF Signal (Saturated Conditions)

When a strong RF signal is present, capturation effect takes place. Noise gain is considerably reduced. The noise gain will be $G_n < G$.

We will resort to the equation, expressing $N_{in(n)}$ under limiting conditions by merely exchanging G by G_n. This approximation is justified if one assumes that the amplifier saturated after a small number of turns compared with a very large number of turns the signal is stored.

$$N_{in(n)} = kTB\left[1 + \frac{B_o}{B}\,\frac{G_nF}{L}\,\frac{(G_n/L)^{n-1} - 1}{G_n/L - 1}\right]$$

For n very large, say, approaching ∞, two cases are of interest.

$\frac{G_n}{L} > 1$ means we still have excess gain of noise.

The same noise buildup will occur as if the saturating signal did not exist. And $\frac{G_n}{L} << 1$ for n very large. $N_{in(n)}$ could be approximated to

$$N_{in(n)} \approx kTB[1 + \frac{B_o}{B} \frac{G_n F}{L} \frac{1}{1 - \frac{G_n}{L}}]$$

$$\approx kTB[1 + \frac{B_o}{B} \frac{G_n F}{L} (1 + \frac{G_n}{L})]$$

As the number of turns approaches infinity, it could be noted from the last equation that the noise will approach a fixed value. This value will highly determine the sensitivity of the FML, since it will be required to have initially a signal level higher than this value.

It is clear that for the correct operation of the loop, $\frac{G_n}{L} < 1$. In other words, there must be "noise suppression." For a large dynamic storage range and good sensitivity, an amplifier with a low noise figure and a large saturated output is required.

An experiment in this condition is presented in [4]. The experiment setup is shown in Appendix A. The delay of the loop used in the experiment was .22 μsec which implies Δf_p = 4.5 Mhz. The input signal was chosen to be greater than -55 dbm.

The result showed on the oscilloscope, the RF stretched stored signal. On the spectrum analyzer, the particular frequency dominated the spectrum, figure 6.

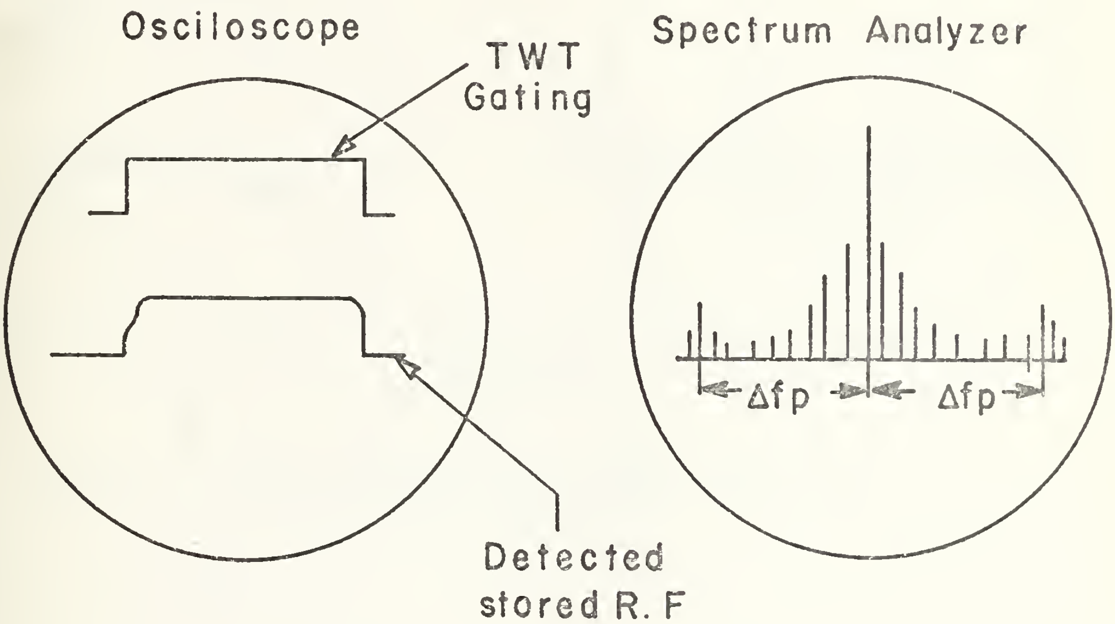


FIGURE 6. Detected Stored RF and Spectrum of Stored Signal.

The injected preferred signal was at least 10 db higher than adjacent frequencies. Obviously one cannot be satisfied with that. It was then expected that if an arbitrary frequency would have to be stored, a shift to the closest particular frequency will occur.

In the same conditions, the experiment was further pursued and a driving signal half way between two preferred frequencies was injected. The result obtained was a rippled detected stored RF and an enhancement of the two adjacent particular frequencies. Figure 7 shows these results.

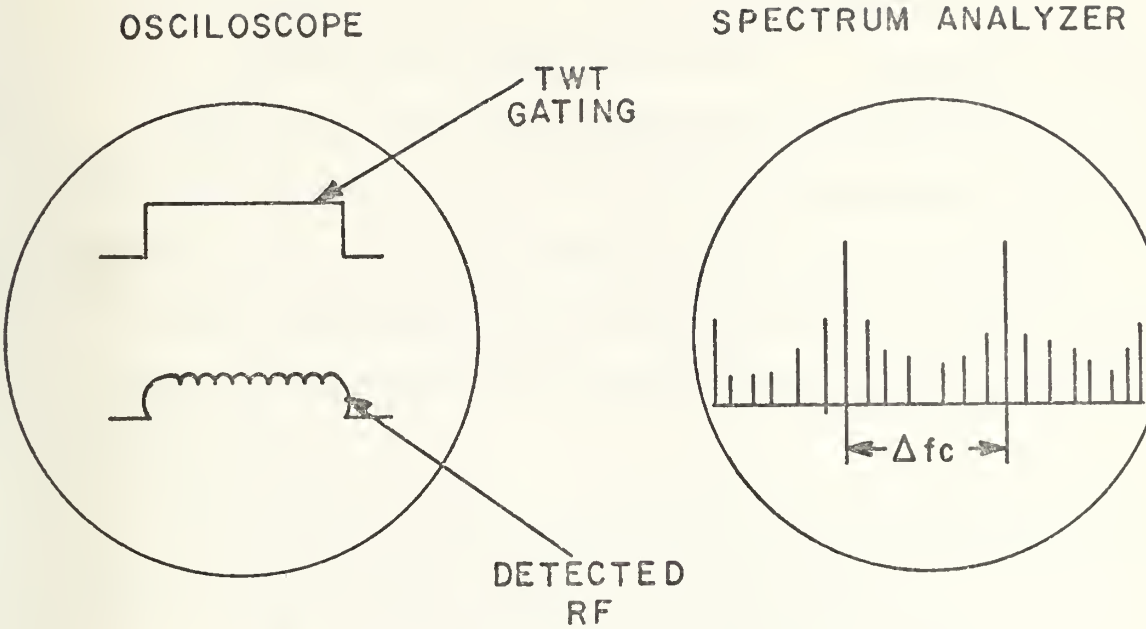


FIGURE 7. Detected Stored RF and Spectrum of the Stored Signal

The position of the resonant frequencies can be controlled by means of helix voltage change in a TWT amplifier or by inclusion of a controlled phase shifter when other amplifiers are in use. By this means, the intercepted signal is made to be resonant to the loop.

D. PARAMETERS DEPENDENCE ON FREQUENCY

In the last sections, the analysis did not take into consideration the variation in the components parameters across the band.

Considering each parameter at a time:

Amplifier's gain -- frequency dependent

Noise figure -- frequency dependent

Noise gain under saturation -- frequency dependent.

The loss in the loop is frequency dependent no matter what the delay line is made of. This is mentioned since the delay line is the chief contributor to losses in the loop.

One could analyze the contribution of every parameter variation separately and probably come up with impressive equations.

The equation that relates all those parameters derived before and repeated here for convenience:

$$N_{in(n)} = kTB[1 + \frac{B_o}{B} \frac{G_n F}{L} \frac{(G_n/L)^{n-1} - 1}{G_n/L - 1}]$$

The critical value for success is $\frac{G_n}{L}$. If it was accepted that $\frac{G_n}{L} < 1$ on the average across the frequency band, it does not mean that for a very narrow frequency band it is not true. If that happens and $\frac{G_n(f_1 - f_2)}{L} > 1$, the frequency band contained in $(f_1 - f_2)$ will allow the noise to take over when n will get large.

The practical approach is the lab bench. It was learned by the author that prior to any mathematical analysis on the feasibility to incorporate solid state amplifiers in an FML, the engineers in charge in Watkins-Johnson performed Noise-Suppression tests; the results of those tests will be discussed later.

Similar tests to those mentioned above have been conducted at Teledyne and described in reference [3]; it is worthwhile to discuss the nature of the tests and to study them.

The test to be explained has been performed on a loop TWT, but there is nothing to prevent the extension to any other desired amplifier.

Low-power broad band noise drove the loop TWT in the small signal mode, and resulting output noise power was measured as a function of frequency through a sweeping Y/G filter. The values were recorded.

The second phase of the test was to drive the amplifier beyond saturation.

While having ability to know what the Gain Compression was, the output noise power was again measured. This test has to be repeated for various frequencies across the band and for different Gain Compressions. Figure 8 shows the block diagram for the test.

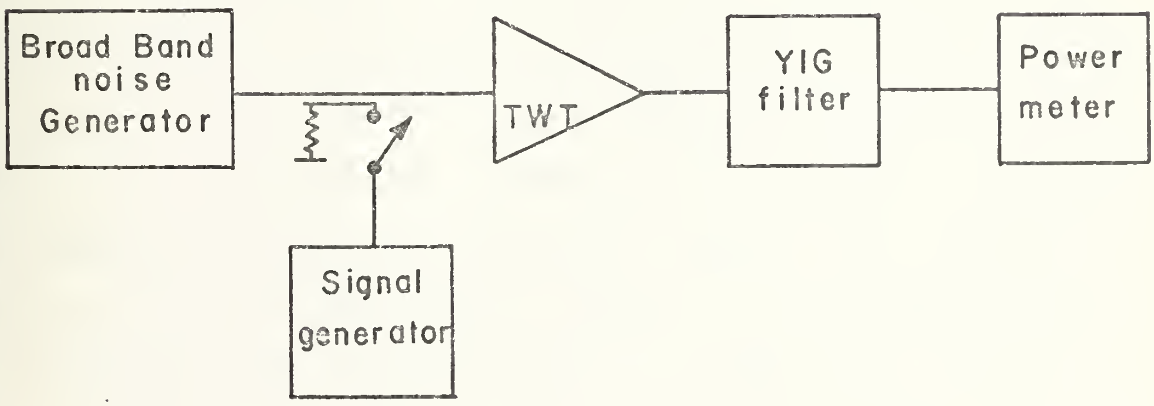


FIGURE 8. Block Diagram for Noise Suppression Test

A sample result of this experiment is shown in figure 9.

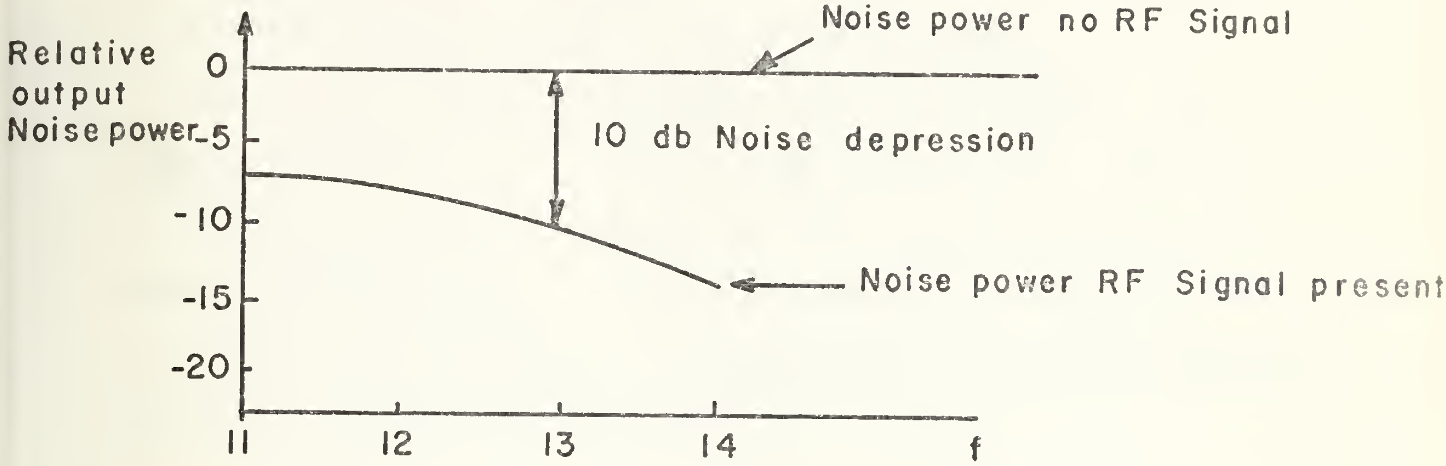


FIGURE 9. Noise Depression Diagram under 7 db Gain Compression at 13 Ghz

Mere observation of figure 9 will reveal that Noise Suppression is increasing across the band. It should not be forgotten that figure 9 represents no dynamic operation and the Gain Compression is a constant value. As for the loop, the compression is increased until stability at the frequency is achieved. The stability will occur when the loop attains unity gain. With behavior demonstrated in figure 9, unless we counter this effect by amplifier design, the frequency to the left of the signal having a smaller noise suppression, will build up even though the desired signal has attained stability. The duration of the memory will extend until the noise surpasses the signal. What we would actually want to see is a constant noise suppression. Recalling:

Noise Suppression db = Noise Depression db - Gain Compression.

Since the noise depression increases with frequency, compensation is achieved by increasing gain compression, which in turn is achieved by the design of the amplifier to have an increasing gain with increasing frequency.

It was previously stated that $\frac{G_n}{L}$ is of concern. The chief contributor to L (loss) is the delay line. Evidently, to restrain the value of $\frac{G_n}{L}$ to certain limits after G_n has been compensated for, L has to be stabilized. Figure 10 [3] is a demonstrative example of delay line loss versus frequency (acoustic delay line K_u band).

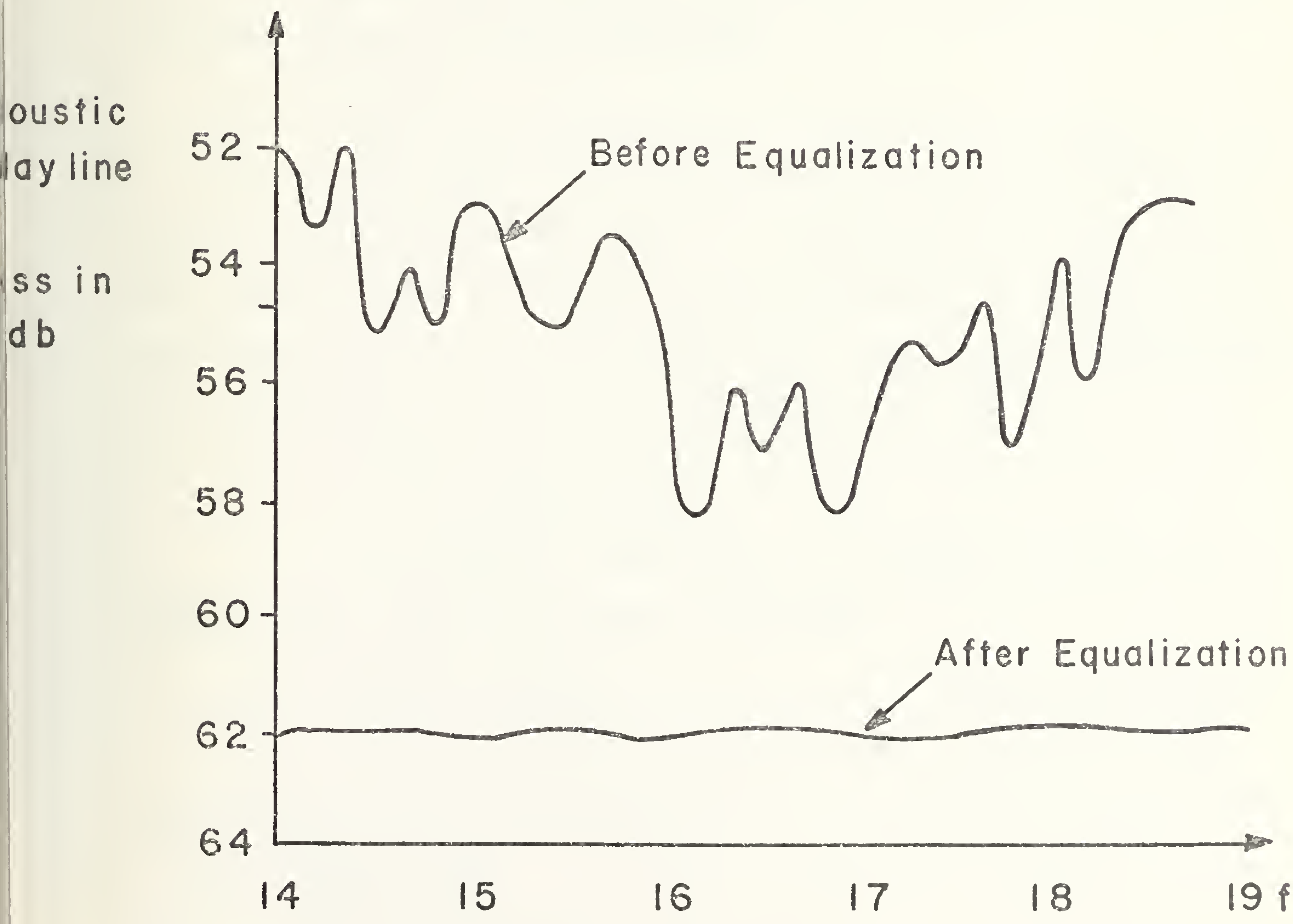


FIGURE 10. Acoustic Delay Time K_u Band vs. Frequency, Before and After Equalization

Equilizers, which consist of a series of cavities, are used to flatten the loss across the band.

E. REQUIREMENTS UPON COMPONENTS

At this point it would be proper to present a summary of the FML components, emphasizing parameters that optimize FML performance.

1. Amplifier

a. Band Width

This parameter is of concern to the user. The application in which the FML is to be used will determine the band width requirement. Nevertheless, a narrower band width will reduce noise problems.

b. Gain

The higher the better. 10 db of excess gain is the minimum gain necessary for storage success. The amplifier should have a flexible gain structure in a manner such that the gain can be tailored across the band to compensate for the components that are frequency sensitive.

c. Noise Suppression

The higher the better. The magic number in industry is 3 db flat across the band.

d. Noise Figure

The lower the better to reduce noise buildup, and to have good sensitivity.

2. Delay Line

a. Attenuation

As low as possible, flat across the band.

b. Temperature Sensitivity

We would like to see the delay line indifferent to temperature, at least not very sensitive. See Appendix B for comparison of different delay lines.

c. Size and Weight

This parameter is dependent upon application of the FML since a tremendous difference exists between the different types of delay lines, for comparison, see Appendix B.

3. Equalizer

This component is essential since no matter how hard we try, the other components have fine structure variations of the gain in the closed loop. After equalization, a 1 db variation is tolerable. The equalizer has to be tunable to allow tuning whenever characteristics drifts occur.

III. SOLID STATE AMPLIFIERS AS REPLACEMENT TO TWT IN FML

The frequency band of interest for FML has continued to be 1-18 Ghz. For this frequency range the amplifier that best fulfilled the qualification mentioned in II.E.1. was the TWT. As for 6-18 Ghz, it is still the best and most adequate.

Reviewing the components composing the FML, the question that could be raised is, which component could be replaced by a more technologically advanced counterpart?

Advantages could be found in the use of acoustic delay lines [3]. Size is greatly reduced and this type of delay line manifests a remarkable temperature stability compared with other types of delay lines. Losses are comparable to coaxial delay lines, but still twice as much as wave guide delay lines (Appendix B). Teledyne Corporation has manufactured an FML utilizing an acoustic delay line. The performance was judged to be good. As for the future, acoustic devices are at a critical development point and their proliferation is dependent on the success of RCA and Zenith experiments which have in view to use other features possessed by those elements usable in mass production TV receivers.

The only FML component that could be thought of to be converted to solid state is the amplifier. Low frequency amplifiers have been very successfully used for some time. The microwave solid state amplifier is a rather recent development. One could find solid state amplifiers ranging up to

18 Ghz and much more. However, the higher the frequency, the higher the noise figure. The power rating goes down when frequency increases.

The need for increasing gain with increasing frequency has been stated; however, this does not yet happen with solid state amplifiers. For frequencies above 4 Ghz, it was difficult to find adequate amplifiers for purposes of study. Below 4 Ghz, industry offers a great amount of good amplifiers that deserved close study. Basically, everything that had more than 35 db gain and had a noise figure less than 7 db and was rated for about 10 dbm, should have gone through a noise suppression test.

The initial intention was to borrow a number of amplifiers and to study the feasibility of incorporating them into an FML. In order to do this, a noise suppression test would have been mandatory. Unfortunately, lack of test equipment lead to the abandonment of this idea.

Contact was made with Watkins-Johnson (W-J) and it was found that the company has already manufactured an FML with a solid state amplifier. It was learned from the engineers at W-J what approach was taken to retrofit an existing FML with a solid state amplifier.

The legitimate question to ask is "Why should one want to make a change to an existing system working satisfactorily?".

There are several reasons: (a) Lifetime of TWT is much shorter than the lifetime of the solid state amplifier. (b) Solid state amplifiers are much more reliable. (c) Power supply is much simpler for solid state amplifiers compared

with TWT. (d) As a result of the noise suppression test, it was revealed that storage duration was longer for solid state amplifier FML.

The tests conducted in W-J were identical to those presented in section II.C. Since a copy of some of the results was obtained, it would be of interest to follow the tests and analyze the results.

The test setup is shown in figure 11. The amplifier was driven into saturation to have 7 db gain compression. The band of interest was 2-4 Ghz. In figure 12(a), the saturating signal was at 2 Ghz. Except for one spur at about 2.3 Ghz, it can be observed that the noise-depression is very close to 10 db across the band. This spur has to be taken care of, or there will always be noise buildup at this frequency. In figure 12(b) the saturating signal was at 3.2 Ghz, again with 7 db compression. It could be observed that this is not as good as it was observed in figure 12(a) and that work on the amplifier had to be done to eliminate the spurs. It could be noticed that close to the saturating signal there is a total chaos. In figure 12(c) the saturating signal was close to 4 Ghz. Still, the noise suppression is not constant. Up to 2.5 Ghz it was much greater than could be tolerated.

The upper line of the graphs represents noise power RF signal absent. The two other scaling lines were obtained by insertion of 7 db and 10 db attenuators.

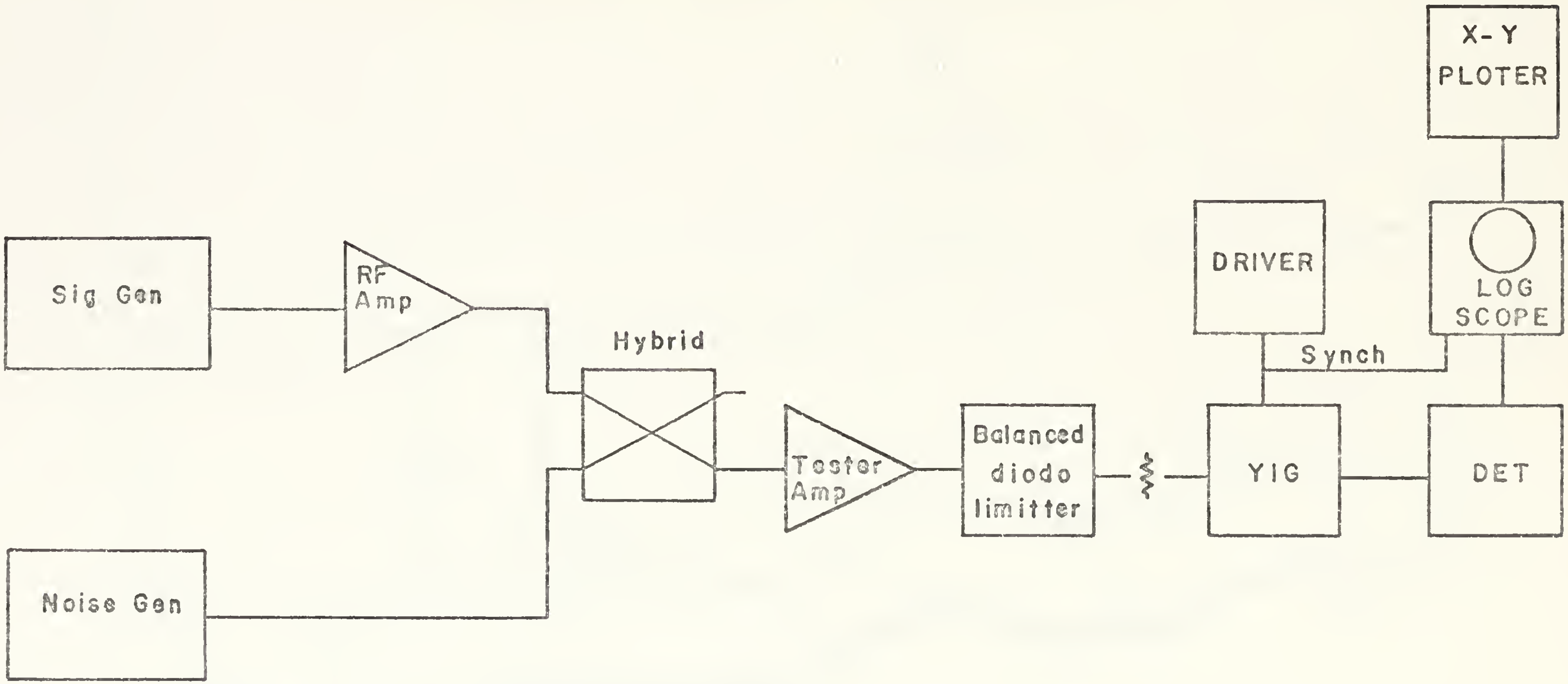


FIGURE 11. Noise Suppression Test Setup Resulted in Figure 11.

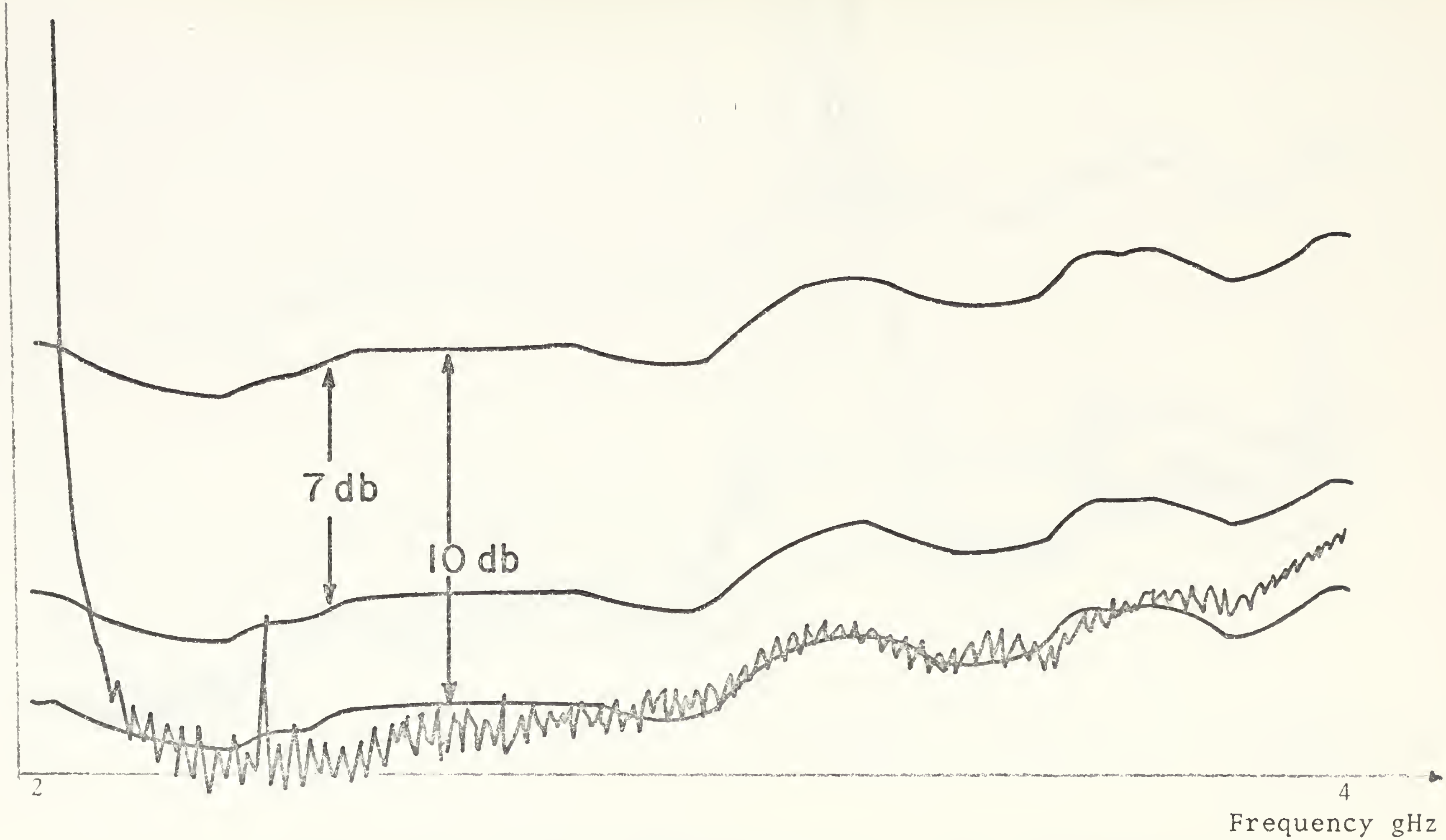


FIGURE 12(a). Noise Suppression Test. Gain Compression 7 db Driving RF 2 gHz.

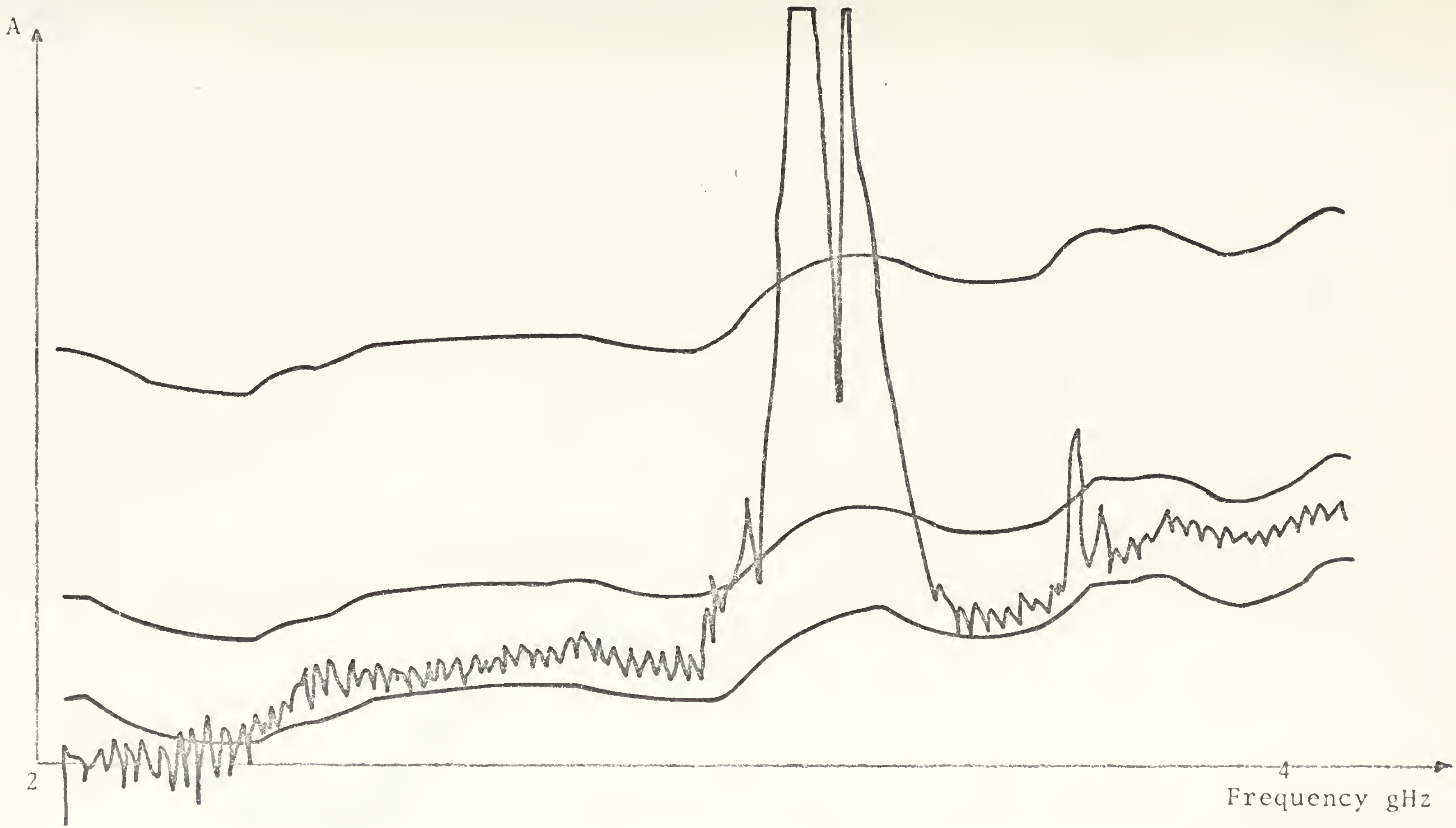


FIGURE 12(b). Noise Suppression Test. Gain Compression 7 db.
Driving RF 3.2 gHz.

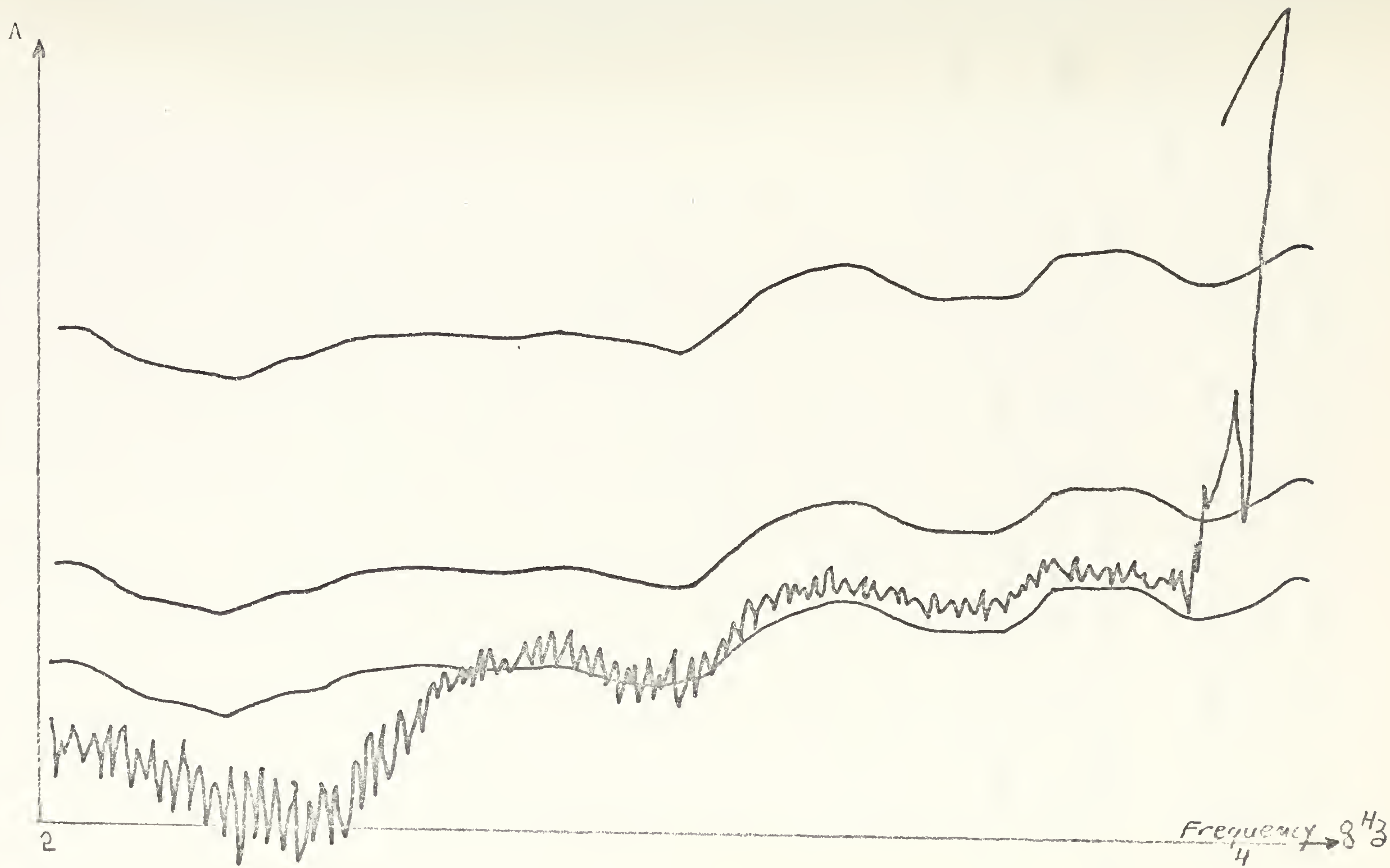


FIGURE 12 (c). Noise Suppression Test. Gain Compression 7 db.
Driving RF 4 gHz.

One may conclude conclusively from these test that, after adjusting, this amplifier would be well utilized in an FML. As indicated before, W-J has put on the market a 2-4 Ghz solid state FML.

It is believed that with time higher frequency solid state amplifiers will show they would replace TWTs in FML.

From this point on, other methods of frequency storage were sought.

IV. ALTERNATE METHODS FOR FREQUENCY STORAGE

It is a difficult task to reveal hidden information about systems which are presently on the design board in industry; the reasons for this are obvious. Even when the new product is ready and offered for sale, the producer is not inclined to explain how it works.

From the beginning of this work an alternate method has been sought. So much has been done in the "digital" world that it was inconceivable that no one had made the attempt to go digital.

Two major limitations were known to begin with: (a) Voltage controlled oscillators and frequency synthesizers are relatively slow responding. (b) Actual sampling rates are not compatible with microwave frequencies.

In the process of search, two new concepts were discovered. Watkins-John's engineers are working on a system that is supposed to be ready in about a year. Not much has been said about this system. Taskar has come out with a new promising concept that will be discussed in detail further on.

A. THE SUGGESTED W-J SYSTEM

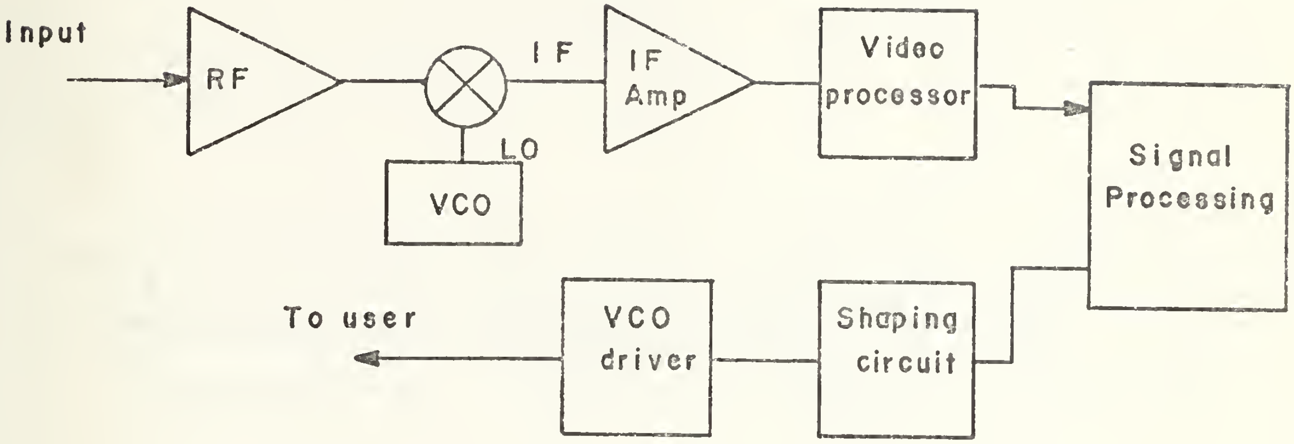


FIGURE 13. W-J Memory Storage System

This system utilizes two VCO's. As a matter of fact, the one used in the receiving portion acts as an LO. From the point of view of memory, this representation as recommended in [7] is too simplistic. There is no indication as to how the storage is obtained by the video processor, an operation that is not at all trivial. From the look at the system, one could further say that the response requirements are not of great concern (since the components in use are slow responding at present).

In private discussions, it was learned that this system is not intended to replace the FML. The above system is intended to promote voltage controlled oscillators.

The system that eventually will replace the FML in W-J is still on the designing board and very little could be said about it; nevertheless, here follows its philosophy of operation.

The incoming signal is beat down to some IF frequency. The IF is sampled and held, then probably stored digitaly. When the signal is requested, the driver converts the stored frequency to the adequate RF frequency. Figure 14 outlines in general the above concept.

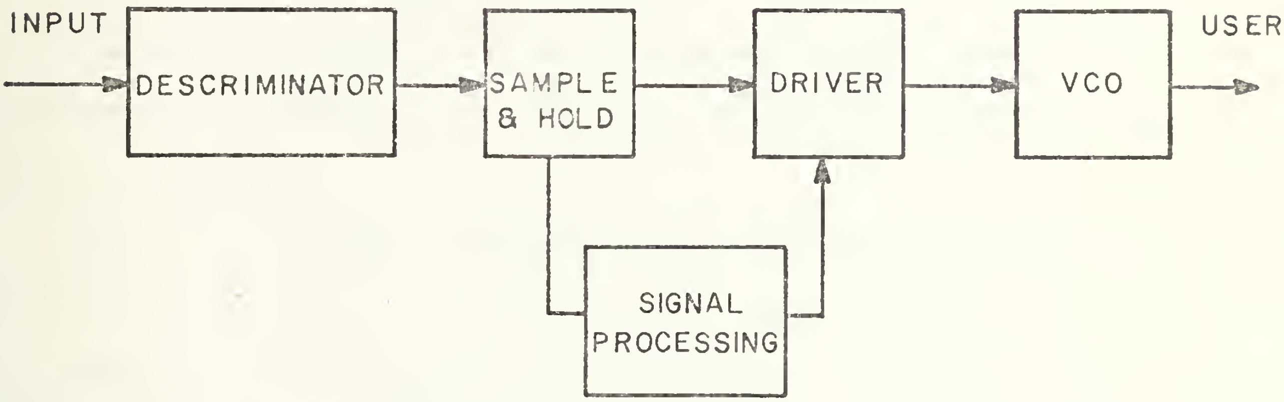


FIGURE 14. W-J Memory System - General Concept

Again, it was not known what problems needed to be overcome. The questions that could come up from this presentation:

a. What had been exactly meant by discrimination?

b. In what dimensions would the sampling operate--time and amplitude or time only--and for how long a pulse was the system intended to work?

c. How fast is the driver (problem mentioned by W-J)?

d. How fast is the VCO?

e. What is the instantaneous band-width?

f. What is the fidelity of the reproduced signal?

In some applications, the user might be interested in the instantaneous reproduction. For traditional TWT systems, one should take into account 8 nsec for each in line tube. In the above represented digital system it is suspected that a much, much larger time is required.

B. MiPS (MICROWAVE PULSE STORAGE), A PRODUCT OF TASKER SYSTEMS

The most attractive microwave storage system right now on the market is available for order from Tasker Systems, a division of Whittaker.

Since this system, surnamed MiPS, standing for "Microwave Pulse Storage", seems to indicate the future trend of frequency storage devices, it might be worthwhile to explain in a more detailed form the principle of operation of the system and its properties.

1. Principle of Operation of MiPS

The MiPS is composed of five main components which are: (a) down converter, (b) digital memory, (c) voltage controlled oscillator, (d) up converter, (e) I/O control.

The received RF signal is down converted to a frequency within an IF band. The mixing frequency for conversion is provided by the VCO which for the moment is being operated at a fixed frequency, hence, acting more like an L.O. The intermediate frequency is sampled in the memory unit and for each positive amplitude reading a one is stored; for each negative reading, a zero is stored. The stored information in the form of zeros and ones can be kept forever. When reproduction is desired, the stored pulse is up converted where again the

mixing frequency is provided by the same L.O. Figure 15 sketches this operation. The PRF is arbitrarily controlled by the input/output control where CW can be obtained by letting PRI = 0.

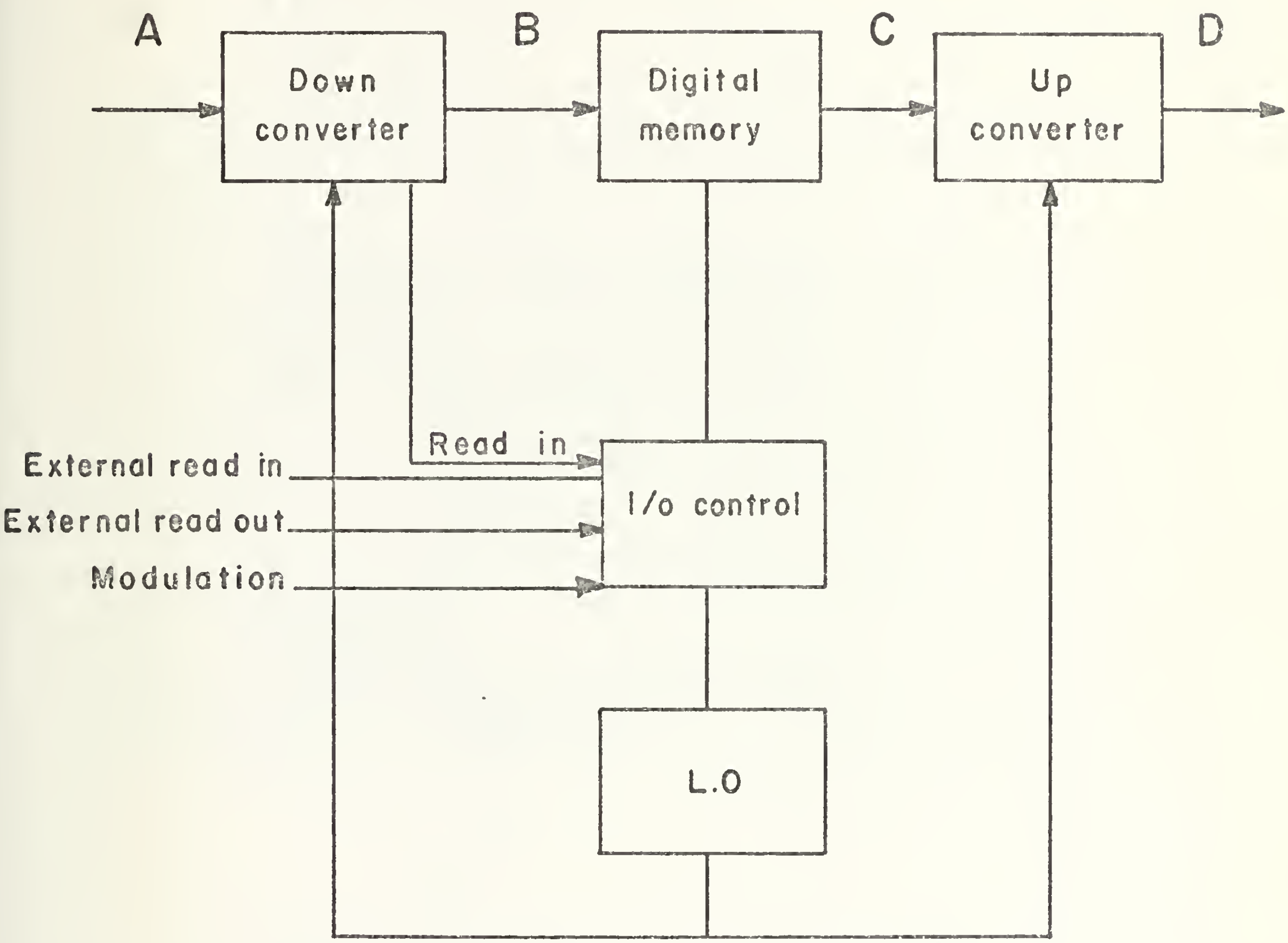


FIGURE 15. Block Diagram of MiPS

Figure 16 shows the signal appearance in the time domain. The chief concern is to obtain the wave-form at D as close as possible to the input at A. It is more instructive to see the similarity or difference between the wave-forms at

A and D, observing the spectrum at these points. Figure 17, taken from Tasker's brochure, shows the indicated spectrums.

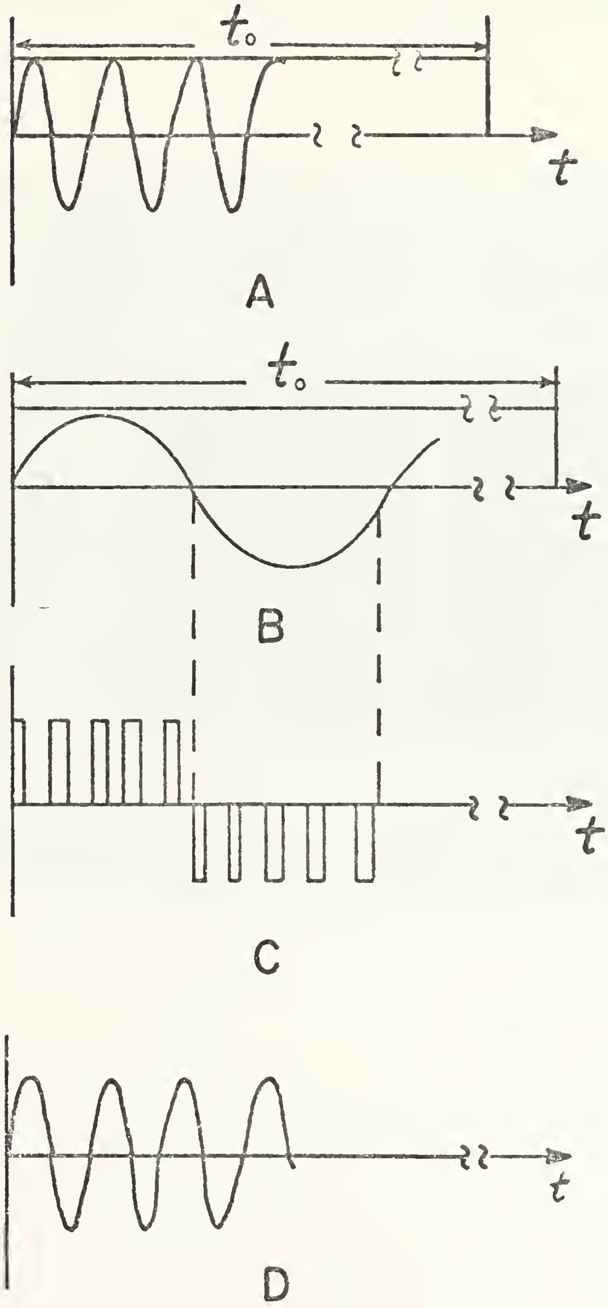
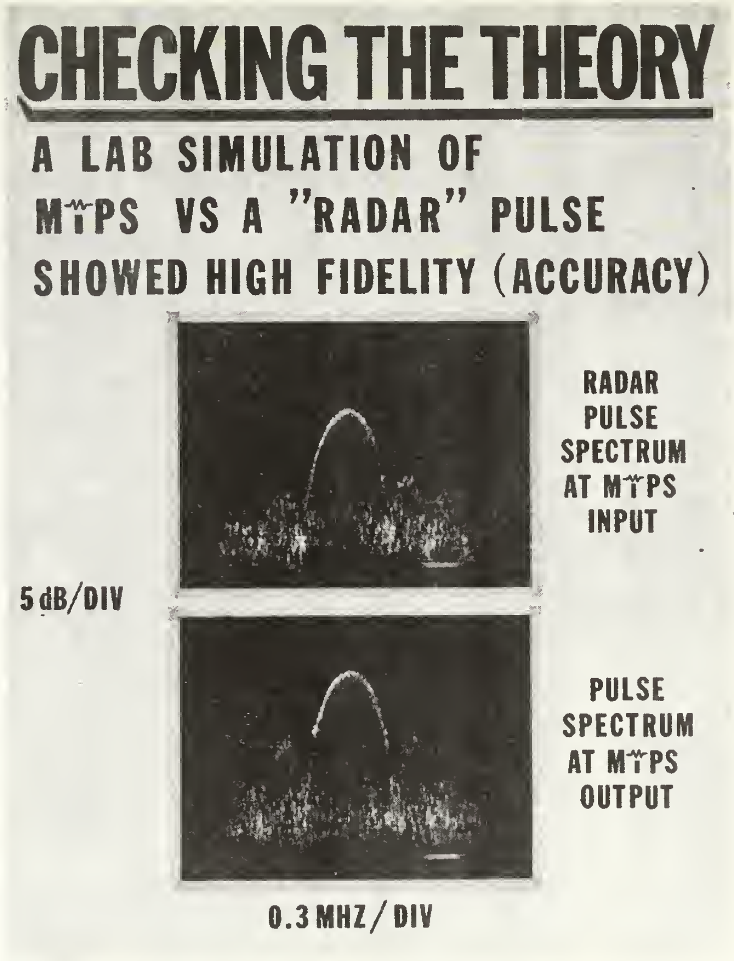


FIGURE 16. Wave Shape in the MiPS Observed at the Output of:

A. RF Amplifier, B. Down Converter
C. Memory, D. Up Converter



Point A

Point D

FIGURE 17.

- INPUT VS OUTPUT SPECTRA SHOW NEGLIGIBLE DIFFERENCES (AND THOSE, PRIMARILY IN 2ND ORDER SIDEBANDS).
- NO CENTER-FREQUENCY SHIFT IS EVIDENT.

It was revealed by the manufacturer that the up converter is a "kind" of a phase modulator. A decision has to be made as to which pulse should be stored. That decision could come from the down converter if every pulse that gets through has to be stored, otherwise the decision could come from an external control. When the decision is made and a signal gets to the I/O control, the memory clock strobes the IF signal into memory. As long as DC power is supplied, the memory retains the stored signal.

One should be aware that both short and long term stability of the reference is of critical importance. The manufacturer assured the author that clock and L.O. are sufficiently stable in order to insure accurate sampling and accurate reproduction. However, this specific problem deserves a close look for a user with specified requirements.

2. Properties of MiPS

a. Band Width

Compared to the FML, MiPS's instantaneous band width is very narrow. While FML has an octave band width or more, MiPS has at most 300 Mhz. There is a direct link between the length of the pulse desired to be stored and the band width. When the narrow band is accepted, longer pulses could be stored. This ties in the memory size, and one could increase band width and pulse length if the memory is increased. When the whole matter is pinned down, what is really required is a much higher sampling rate. Figure 18 shows signal length capacity versus band width where the sampling rate is a fixed value.

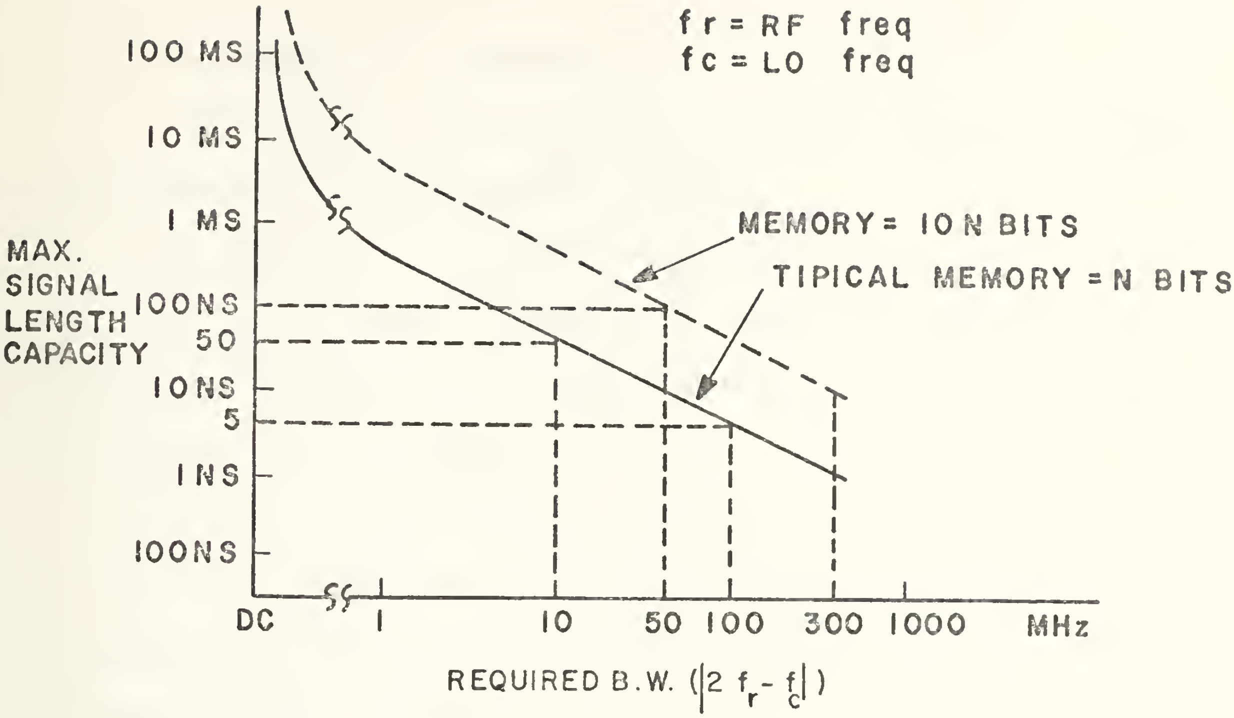


FIGURE 18. Signal Length Capacity vs. B.W.

b. Fidelity of Output Signal

The manipulation on the input signal from the front end to the output (mixing, sampling, up converting, etc.) create side lobes that might be considered as noise. It was revealed that for a single tone RF input, the reproduced RF is as indicated; not pure, and its first side lobe is 10 db below the wanted RF.

c. Phase Conservation

The way the system stores the signal added to the fact that the L.O. is stable and is running constantly, the reproduced signal would be coherent with respect to the transmitting systems. Whether this is desired or not, it is a matter of user specifications; in most cases it is an advantage. The most appealing use due to this property is for correlation purposes.

d. Modulation Conservation

Frequency and phase modulations will be conserved within the pulse length memory storage.

e. Modulation to Reproduced Signal

The control on the L.O. enables the user to exponentially modulate the reproduced signal to simulate doppler shift or any other effect.

f. C.W. Operation

As indicated before, by controlling the interval between pulses on reproduction C.W. is obtained by letting the interval be zero. However, this will not be a smooth sine wave since the leading phase of the stored pulse is not locked with the trailing phase of the stored pulse. When C.W. is generated, the same pulse is repeated back to back and a phase jump will occur every time one pulse is ended and a new one just starts.

It is to be noted that there is a possibility to sweep the V.C.O., hence to increase the overall band width; again, this is a user option.

The goal of this section was to present the technical aspects of the system. More detailed data may be obtained from Tasker's technical notes.

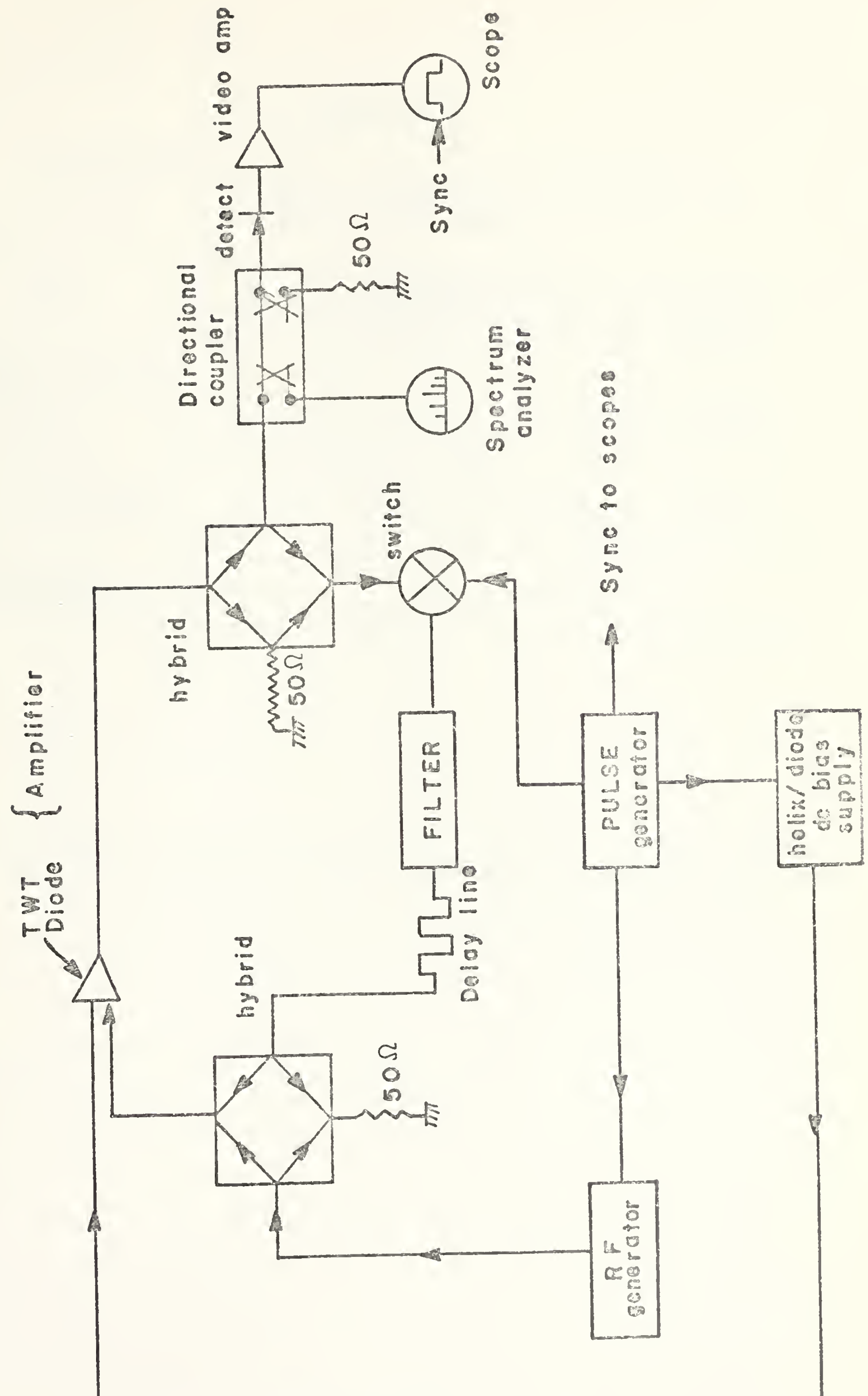
V. CONCLUSION

The breakthrough in microwave frequency storage is here. While the first generation models are at hand, other companies are probably pondering some futuristic system which will soon be available.

The trend is to go completely digital. The flexibility obtained by digital storage is immense. Technological obstacles such as band width, sampling rate and response time will probably be overcome soon.

In the meantime, traditional FML with modernized components will continue to be widely used. Further use of solid state amplifiers is obvious, in view of the much improved results obtained. One could also expect suitable amplifiers for FML in higher frequency than 4 Ghz. As for the delay line, the question is not independent of amplifiers in use. For the TWT FML's there is no reason why acoustic delay lines would not replace the bulky wave guide and coaxial delay lines. If incorporation of solid state amplifiers and acoustic delay lines is sought, achievement would depend upon the development of the amplifiers since as noted before acoustic delay lines are at present very lossy.

The indication to go digital is especially enhanced in the military community where multi-purpose computers are to be part of the whole system. Needless to say, digital systems are readily adaptable to computers.



"Memory Loop" Performance Measurement Setup

APPENDIX B

COMPARISON OF DELAY LINES SPECIFICATIONS [3]

KU Band 200ns Delay

Type	Loss at Temperature *			Volume in ^{3}
	-54° C.	25° C.	95° C.	
Wave Guide WR-62	13 db	18 db	22 db	$\approx$ 1300
Coaxial (.285 Diam)	31 db	45 db	57 db	$\approx$ 200
Acoustic Bulk Wave	45 db	46 db	46 db	< 1

* The loss represents an average loss across the band.

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